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BUREAU OF MINES
R. R. SAYERS, DIRECTOR

INFORMATION CIRCULAR

HEALTH HAZARDS FROM INADEQUATE COAL-MINE VENTILATION

BY

R. R. SAYERS

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

HEALTH HAZARDS FROM INADEQUATE COAL MINE VENTILATION[1/]

By R. R. Sayers[2/]

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INTRODUCTION

Underground conditions that require ventilation are general foulness of the mine air caused by the presence of decaying organic matter, emanations from the lungs and bodies of workers and animals, quantities of dust, or low concentrations of toxic or noxious gases.

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MINE GASES

The underground atmosphere may be hazardous to life or health through lack of oxygen or contamination by a number of harmful gases known to many miners as black or choke damp, firedamp, white damp, and afterdamp (1)3/ but referred to by most mining men by their principal constituent, as nitrogen, methane, carbon dioxide, or carbon monoxide. Oxides of nitrogen, sulfur dioxide, and hydrogen sulfide (stink damp) also may be present under certain conditions in concentration high enough to be dangerous.

Mine gases may be classified as asphyxiants or irritants (2). The asphyxiants may be subclassified as simple asphyxiants and chemical asphyxiants. The simple asphyxiants are inert physiologically, although they may be active chemically. They exclude oxygen from the lungs. The chemical asphyxiants have some property that makes small quantities in the air have an asphyxiating action without excluding oxygen from the lungs. They either act on the blood to prevent it from transporting oxygen or on the tissues to prevent them from using the oxygen when it is brought to them by the blood.

The irritant gases are those regarded as corrosive from the chemical standpoint. They injure the surface tissues and thus induce inflammation of the respiratory tract and the lungs. The difference in the effects of the various irritant gases depends chiefly on their solubility.

Asphyxiants

Oxygen Deficiency

When normal air, which contains about 21 percent (20.94 percent) oxygen, is circulated through a mine it loses some of its oxygen by the breathing of men and animals; oxygen is consumed in mine fires and in explosions of methane or coal dust or both; a certain amount is absorbed by the coal and timber or combined chemically with minerals such as pyrite and marcasite; the oxygen thus absorbed is replaced largely by the carbon dioxide, which is given off by the coal and decaying timbers and by the breathing of men and animals; moreover, the oxygen content of the air may be diluted by intrusion of extraneous strata gases, such as nitrogen, carbon dioxide, methane, and hydrogen sulfide, or by gases formed by action of chemicals in mine water on minerals or rocks.

The effects of breathing air deficient in oxygen vary with the amount or degree of the deficiency. If complete anoxemia is

3/ Numbers in parentheses refer to bibliography at end of circular.

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produced suddenly, loss of consciousness occurs immediately and without previous warning symptoms. A miner who breathes pure or nearly pure methane or nitrogen drops as though he had been felled, and when he recovers after breathing fresh air for a few seconds he sometimes imagines that he has been knocked down by another man and may act accordingly. If the anoxemia results with moderate rapidity, marked temporary disturbances in breathing and circulation as a rule give some warning of what is coming. If the onset is gradual and without exercise, little or no preliminary discomfort is experienced, therefore lack of oxygen is very dangerous. Some investigators (3) state that the percentage of oxygen should never drop below 19 and that the carbon dioxide increase should never exceed 1.25 percent in mines. In defining pure intake air, the Mine Safety Board of the Bureau of Mines decided that for health and safety the air should contain not less than 20 percent oxygen (dry basis).

When air of diminishing oxygen content is breathed, symptoms appear at different oxygen pressures in different individuals, depending on health, physical fitness, and age. Schneider (4) found that during rebreathing tests in the medical research laboratory of the Air Service, a few men experienced an increase in lung ventilation with the first decrease in the oxygen percentage of the air breathed, which increased gradually in inverse ratio to the reduction in oxygen. More than 50 percent of the men examined, however, gave the first respiratory response at 16 to 14 percent of oxygen; 25 percent responded first at a lower percentage; and a few gave no response. The response was slight in most subjects but became more pronounced when the available oxygen had decreased to 12.5 to 9 percent. With 8 to 6 percent oxygen, most of the men breathed 5.5 liters more than at the beginning of the experiment, and depth of breathing increased 20 to 128 percent. When the minute volume of breathing failed to increase or increased only slightly (1 or 2 liters) as the amount of oxygen inhaled decreased, lung ventilation was insufficient, and the subject could not tolerate as low an oxygen tension as the man whose breathing gradually deepened as the available oxygen decreased.

The body adapts itself to some extent to lowered percentages of oxygen in the air breathed; that is, the anoxia that would exist without adaptation is greatly diminished, as in persons living at high altitudes, or the tissues may adapt themselves to a lower partial pressure of oxygen. The theory is that acclimatization takes place in three ways: (a) By increase in the number of red cells available to carry oxygen in the blood; (b) by increase in ventilation of the lungs; and (c) possibly by active secretion of oxygen into the blood by the lungs. Experiments, however, show that animals cannot be acclimatized and live long at altitudes above 18,000 feet; they can live in a concentration of oxygen equal to 12 percent of 1 atmosphere, but not for more than 6 weeks in a concentration equal to 10 percent (5). Owing to lack of oxygen, deterioration

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sets in, and the animals finally show degeneration of certain organs; they recover if exposure to the low concentration of oxygen is terminated before deterioration has advanced too far. Peters and Van Slyke (6) state that according to general observation, residence at altitudes higher than 10,000 feet appears frequently to lead to premature cardiac failure.

Simple Asphyxiants

Nitrogen.- Large quantities of this gas, which forms 78.09 percent of normal air, may be present in many poorly ventilated mines; varying quantities may be mixed with carbon dioxide and oxygen. It is not combustible and will not support combustion. A limited amount is held in coal, and nitrogen intrusions from rock strata are not unusual. An instance is given (7) of the accidental death of two men in a French coal mine owing to a comparatively small but regular nitrogen blower. Nitrogen is not a toxic gas, but it cannot support life in the absence of oxygen; its effect is due to its action as a diluent of the oxygen of the air. A German report (8) regarding the effects of nitrogen in a submarine, in which the oxygen supply was cut off unnoticed by the crew owing to damage to the vessel (the carbon dioxide content of the air was fixed by an alkali) states that the absence of oxygen is unnoticed by the victim, that he feels better and conjures up pleasant mental images and thoughts accompanied by wish phantasies, and that he then falls suddenly as though stricken by apoplexy; if he is not removed from the dangerous environment, he will die in a short time.

Methane.- This gas, sometimes called firedamp, is combustible. It occurs in mines mixed with various amounts of oxygen, nitrogen, and carbon dioxide. There is always the risk in mining, especially in coal mining, of drilling into a pocket of methane. Pure methane is colorless, odorless, and tasteless. In certain concentrations it burns in air or oxygen with a pale-blue flame. It is not a supporter of combustion in the generally accepted meaning and unmixed with air quickly extinguishes a lamp flame; however, mixed with air in certain proportions - approximate limits of inflammability in air, 5.3 to 14 percent by volume (9) - it is explosive. Although methane is nontoxic it may so dilute the oxygen of the air as to produce the effects described in the discussion of oxygen deficiency.

Carbon dioxide.- Carbon dioxide is a colorless, odorless gas having an acid taste. It is a product of complete combustion of carbon or carbonaceous matter; it is also a product of the decomposition of organic compounds and of the respiration of men and animals. It will not burn or support combustion, and it is heavier than air. Excess carbon dioxide in mine air generally is associated with oxygen deficiency. Owing to its high specific

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gravity, it usually collects along the floor in low places where it is formed or where it emanates from the rock strata. It is likely to be found in long, unventilated dead ends and in winzes, especially where porous strata and fissured lodes exist. Carbon dioxide emanates from the rock strata in underground workings of certain mines, notably in the Cripple Creek (Colo.) and Tintic and Park City (Utah) districts, as well as in some mines in Europe; in July 1930 an outburst of carbon dioxide in a coal mine in Silesia killed more than 150 persons, some of whom were hurled to death by the explosive violence of the outburst, but most of those killed were asphyxiated by the very rapid flooding of the workings with carbon dioxide gas (10).

In experiments conducted by Bureau of Mines investigators (11), about 2 percent of carbon dioxide in oxygen produced a slight increase in lung ventilation but no subjective symptoms; 5 percent in oxygen caused a noticeable increase in lung ventilation but no other signs or symptoms; 7.2 percent produced a marked increase in lung ventilation, moderate sweating, and a slight fullness in the head after the mixture had been breathed for 10 minutes; 9 to 10 percent produced about a 300-percent increase in lung ventilation, and the subjects complained of frontal headache and were dizzy and sweating at the end of 10 minutes. About 9 percent of carbon dioxide in oxygen was breathed by some of the subjects for as long as 45 minutes, but the breathing was very laborious and dizziness, headache, and sweating were marked. In fact, to have done any work while breathing this mixture would have been extremely difficult. However, the minds of the subjects remained clear. All observations were made with the subjects seated. From these data it was concluded that, although it is possible to breathe 9 to 10 percent of carbon dioxide in oxygen, any percentage above 5 will cause noticeable effects, and 2 1/2 percent is the highest concentration that should be permitted in the inspired air of a self-contained oxygen breathing apparatus at any time.

Chemical Asphyxiants

Only two substances are classed as chemical asphyxiants - carbon monoxide and cyanide (2). Carbon monoxide is the only one found in mine air.

Carbon monoxide.- Carbon monoxide, frequently called "White damp," is a colorless, tasteless, and for ordinary purposes odorless product of incomplete combustion of carbonaceous materials. Its specific gravity is slightly less than that of air. "white damp" is a term applied by miners to the white mist or steam that under some conditions arises from spontaneously heated coal. Although carbon monoxide is the principal toxic constituent of white damp, the latter term is misleading, as carbon monoxide is

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a colorless gas and may be present in mine air from other sources, such as explosions of gas or coal dust, mine fires, and explosives used in blasting.

Afterdamp - a mixture of air, nitrogen, carbon monoxide, and carbon dioxide - is produced by mine fires, the explosion of methane or coal dust, or both. All explosives apparently evolve some carbon monoxide, and some are likely to give off oxides of nitrogen as well as other toxic gases. Black blasting powder produces both carbon monoxide and hydrogen sulfide; in cases of gas poisoning it is often difficult to decide which gas has been responsible. When explosives containing nitrogen burn instead of detonating, nitrogen may be converted to oxides of nitrogen.

Afterdamp may contain as much as 8.6 percent carbon monoxide, and a large amount of carbon monoxide is given off by smoldering fires, so that the gases from a fire may be much more dangerous than the afterdamp of an explosion and from a practical standpoint produce essentially the same effects and require the same precautions. Some explosives produce much carbon monoxide and others little; hence, there is always risk of carbon monoxide poisoning from the gases from blasting where explosives are used unless ventilation is adequate. In fact, carbon monoxide constitutes a decidedly dangerous hazard in mine blasting, as it is generated both by the dynamite fired and by the fuses burned, and its harmful effects may be augmented by the simultaneous presence of other noxious gases such as carbon dioxide, hydrogen sulfide, or oxides of nitrogen. It is formed particularly in raises, winzes, and development ends after firing. No mine is free of fire hazards, and great loss of life has occurred from the burning of a few cords of timber or even of a box of explosives; in confined spaces these give off enough deadly fumes to kill several hundred men, if they are trapped in a mine where ventilation is defective (10).

The approximate amount of carbon monoxide in gases evolved by blasting in mines is given in the following analyses by the Bureau of Mines gas laboratory (12):

	CO by volume, percent
Mine explosion, immediately after dust explosion (experimental).....	8.0
Mine explosion, 1 day after explosion in coal mine.....	1.0
Mine fire.....	1.0
Blasting with 40-percent gelatin dynamite, 7 minutes after shooting 100 sticks.....	1.2

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	CO by volume, percent
Blasting--	
Products of combustion of black blasting powder	10.8
Products of combustion of 40-percent nitroglycerin dynamite	28.0
Products of combustion of 40-percent ammonia dynamite	5.0

If the amount of carbon monoxide in the gases from blasting is known, the amount of dilution necessary to reduce this gas to a harmless percentage can be calculated (13). In blasting a round in which 16.48 cubic feet of carbon monoxide were formed, it would be necessary to dilute the gases from blasting with about 82,000 cubic feet of air to reduce the carbon monoxide from 0.30 percent to 0.02. In an unventilated 5- by 7-foot drift the gas would have to be diffused evenly over a distance of about 2,340 feet to attain this condition. In other words, it would not be safe for men to return to work in a long, unventilated drift of this size until the gases from the blast had been diffused over a distance of 2,340 feet from the face. Should an explosive be used that formed only 6.5 cubic feet of carbon monoxide when blasted, the distance over which the gases would be required to be evenly diffused would be about 910 feet.

Carbon monoxide acts on man by diminishing the quantity of oxygen that can be carried by the arterial blood from the lungs to the body tissue, thus interfering with the oxygen metabolism. The affinity of carbon monoxide for the blood is about 300 times that of oxygen, and even if only a small amount of the gas is present in the air breathed into the lungs it will be absorbed by the hemoglobin in preference to oxygen. For a person at rest, it has been assumed (14) that 80 percent of the equilibrium values is attained after the following periods:

Concentration of carbon monoxide in air (inclusive), percent	Blood saturation (80 percent of approximate equilibrium values), percent	Time, hours
0.02 - 0.03	28 - 30	5 - 6
.04 - .06	36 - 44	4 - 5
.07 - .10	47 - 53	3 - 4
.11 - .15	55 - 60	1-1/2 - 3
.16 - .20	61 - 64	1 - 1-1/2
.20 - .30	64 - 68	1/2 - 3/4
.30 - .50	68 - 73	1/20 - 30
.50 - 1.00	73 - 76	1/ 2 - 15

1/ Minutes.

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With a given blood saturation, the character and severity of symptoms acquired during exposure to carbon monoxide depend on the time required to attain that saturation and the degree of muscular activity - in other words, the extent of oxygen deprivation. The number of symptoms decreases with the rate of saturation, with high concentrations the victim may experience only a few (weakness and dizziness). If a given saturation has been acquired by long exposure to a low concentration, the symptoms and aftereffects are likely to be much more severe than if it has been acquired by a short exposure to a high concentration. Muscular activity increases the number and accentuates the character of the symptoms during exposure; it also brings out latent symptoms after exposure. A person at rest may pass into dizziness and unconsciousness without experiencing any marked previous effects. In general, the predominating symptoms accompanying the various percentages of saturation are as follows:

Blood saturation, percent:	Symptoms
0 - 10	No symptoms.
10 - 20	Tightness across forehead; possibly slight headache, dilation of cutaneous blood vessels.
20 - 30	Headache; throbbing in temples.
30 - 40	Severe headache, weakness, dizziness, dimness of vision, nausea and vomiting, collapse.
40 - 50	Same as previous item with more possibility of collapse and syncope; increased respiration and pulse.
50 - 60	Syncope, increased respiration and pulse; coma with intermittent convulsions; Cheyne-Stokes's respiration.
60 - 70	Coma with intermittent convulsions; depressed heart action and respiration; possible death.
70 - 80	Weak pulse and slowed respiration; respiratory failure and death.

In addition to the concentration of carbon monoxide in the air breathed, length of exposure, rate of respiration, and presence of other toxic gases, factors governing physiological reaction are the physical condition and age of the victim.

Irritants

The irritant gases found in mines include oxides of nitrogen, sulfur dioxide, and hydrogen sulfide.

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Oxides of Nitrogen

Oxides of nitrogen may be present in mine atmospheres when nitroglycerin, blasting gelatin, dynamite, or other high explosives are burned rather than exploded or when the explosion or detonation is defective or incomplete; the concentration also is likely to be high in case of a blown-out shot. Haldane (14) found that when nitroglycerin was exploded the gases of combustion were 63.2 percent carbon dioxide and 31.6 percent nitrogen but that when it was burned in the presence of its own gases the gases of combustion contained 35.9 percent carbon monoxide and 48.2 percent nitric oxide. On contact with air the latter gas is oxidized immediately to peroxide and other oxides of nitrogen. Peroxide of nitrogen probably is the most irritating of any of the oxides of nitrogen.

Fumes of oxides of nitrogen are treacherous because persons subjected to a concentration that produces only slight irritation of the eyes or respiratory passages at the time of exposure may die within the next day or two from acute inflammation of the lungs and air passages.

Sulfur Dioxide

Sulfur dioxide in mine air almost always indicates a mine fire; however, sometimes it is produced by the detonation of explosives, especially in the blasting of certain sulfide ores. It is very likely to be present in gob fires in which iron or copper pyrites is burning (15).

Sulfur dioxide is a colorless, suffocating, irritating gas with a strong, pungent, sulfurous smell. Even relatively small percentages are poisonous. One part in 500 is almost intolerable to breathe and is very irritating to the eyes and respiratory passages. In moist air sulfur dioxide changes quickly to sulfurous acid, which readily dissolves in water to form sulfuric acid. This happens when it reaches the exposed moist mucous membranes.

Irritation from fumes of sulfur dioxide may begin with as low a concentration as 0.01 part in 1,000 parts of air; susceptible people are made ill by 0.03 part; and animals are killed in 10 minutes by 0.8 part, with dyspnea, cyanosis, convulsions, and catarrhal or croupous inflammation of the respiratory tract. Usually men can develop tolerance to relatively high concentrations, apparently without injury.

Hydrogen Sulfide

Hydrogen sulfide - called "stink damp" from its odor, which resembles that of rotten eggs - is a colorless gas and usually is

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a product of the decomposition of sulfur compounds. Considerable amounts often are formed by the use of black blasting powder or dynamite in blasting sulfide ores. Enough hydrogen sulfide has been found in coal and some noncoal mines during normal operations to cause severe eye irritation (12). In some instances the presence of hydrogen sulfide has been attributed to decomposition of organic debris.

Considerable hydrogen sulfide, which is readily soluble in water, is released from water streams encountered in mining; it is found sometimes in stagnant water underground, particularly where ventilation currents are absent, and great care must be exercised when accumulations of such waters are disturbed.

The following physiological response attends exposure to various concentrations of hydrogen sulfide by volume in air (16):

Subacute poisoning, with slight symptoms such as mild conjunctivitis and respiratory-tract irritation, occur after an exposure of 1 hour to 0.005 to 0.010 percent hydrogen sulfide;

0.02 to 0.03 percent causes marked conjunctivitis and respiratory-tract irritation after 1 hour of exposure;

0.05 to 0.07 percent is dangerous in 1/2 to 1 hour;

0.07 to 0.10 percent causes rapid unconsciousness, cessation of respiration, and death; and

0.10 to 0.20 percent causes rapid unconsciousness, cessation of respiration, and death in a few minutes.

MINE DUSTS

One of the principal safety, efficiency, and health problems confronting mining men is eradication of dust from mines and mining plants, or so diminishing or diluting it that it will not be a menace to the mine or plant and the workers therein.

Dust containing free silica (quartz, flint, and chert) is probably the most harmful ordinarily found in underground coal-mine workings.

Sources of Dust in Mines

A study by the United States Public Health Service (17) of the incidence of dust diseases in the bituminous-coal mines of

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Utah revealed that the dustiest operations were associated with the underground occupations of hand loading, undercutting, rock dusting, and drilling. Hand loaders were found to be exposed to weighted average dust concentrations of 38; undercutters, 34; rock dusters, 34; and drillers, 26 million particles per cubic foot of air. The dust exposure for other underground workers ranged from 4 million particles per cubic foot for timbermen to 23 million for rock workers. The dustiest occupations above ground were found in the tipple. Car loading, with a dust concentration of 119 million particles per cubic foot, exceeded all other occupations. The next greatest concentrations in the tipple were for car dumpers and couplers, rope tenders, and switchmen, who were exposed to approximately 30 million particles. The only occupation above ground, with the exception of the tipple, that had a high concentration of dust, was sand drying, with 98 million particles; all other surface occupations had 5 million particles or less.

Physiological Effects of Mine Dusts

Statistics (18) indicate that much higher morbidity and mortality rates from pulmonary diseases are experienced in dusty than in nondusty industries, especially where dust containing free silica is used or produced.

The principal pulmonary diseases to which coal miners are subject are bronchitis, influenza and pneumonia, pulmonary tuberculosis, anthracosilicosis, and silicosis.

Medical examination of 507 bituminous-coal-mine workers in Utah (17) revealed the presence of anthracosilicosis, a modified form of silicosis due to inhalation of silica admixed with large amounts of carbon dust, which may occur during mining or processing of bituminous coal. Diagnosis of the disease among bituminous-coal miners in Utah was based upon characteristic X-ray findings, symptoms and physical findings, and a history of several years' employment in bituminous-coal mines. It is thought that the exposure of these men to free silica (SiO_2) resulted from rock work, the handling of coal containing bony, rock dusting, and the dispersion of fine sand in the haulageways. Five samples obtained near the face workers ranged in total silica content from 3.2 to 68 percent, while the quartz content of these samples ranged from 1 to 11 percent. Anthracosilicosis was found in 16 (3.2 percent) of these bituminous-coal-mine workers. Fifteen of these 16 workers showed evidence of first-stage anthracosilicosis with but little disability, one worker showed evidence of second-stage anthracosilicosis with moderate disability, and in no instance was third-stage anthracosilicosis found with severe or total disability.

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Anthracosilicosis was found only in workers whose principal occupation was in the mines; no cases were found among tipple or other surface workers. Thirteen cases occurred among men working at the face and three among transportation workers. The incidence of anthracosilicosis among the 346 underground workers was 4.6 percent; 26 cases of early or borderline anthracosilicosis were also found among this group. The X-ray changes, symptoms, and physical findings in all these cases were similar to those discovered by the Public Health Service in previous medical studies of anthracite miners, pottery workers, and pegmatite miners.

Among underground workers, the incidence of anthracosilicosis increased with increasing weighted average dust concentrations and increasing duration of employment. Anthracosilicosis was not found among workers with less than 10 years of employment in bituminous-coal mines and was found in only two instances among men working in an average weighted dust concentration of less than 20 million particles per cubic foot of air. Duration of employment was important, as the incidence of anthracosilicosis rose from 1.7 percent for those employed 10 to 19 years and 5.1 percent for those employed 20 to 29 years to 22.5 percent for those employed 30 or more years.

Previous employment in bituminous-coal mines outside of Utah was found to be an important factor in this study, as 10 of the 16 cases of anthracosilicosis observed gave a history of employment in other sections of the United States or in England. These 10 men with a varied coal-mining experience had averaged 16.2 years in Utah coal mines and 17.6 years in other bituminous-coal mines.

In England during 1936, the Home Office asked the Medical Research Council to investigate the problem of chronic pulmonary disease among the South Wales coal miners. The field investigation was completed in 1941 by the Committee on Industrial Pulmonary Disease (19). The Committee found that the standard of diagnosis for compensation of silicosis is too restrictive in that it prevents compensation for a disabling pulmonary disease contracted in the South Wales coal fields that apparently is occupational in origin. In its report the committee stated that the X-ray criterion is based essentially upon experience of silicosis in other occupations and excludes those cases of pulmonary disability in which the radiographs show only reticulation, although the investigation established the fact that such cases are true instances of occupational disease. For purposes of compensation, the committee recommended that "the X-ray standard required for the diagnosis of the 'pneumokoniosis of coal workers' should include reticulation as well as nodulation and consolidation."

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It also stated in part that--

> Although the Committee recognise certain distinctions between the pulmonary abnormality found typically in colliers and that found typically in hard-heading workers, they believe that differentiation between the two conditions is impracticable in routine work, and that one term is preferable to cover both. They, therefore, recommend the use of the comprehensive term "pneumokoniosis of coal workers" for all the pulmonary conditions described as due to dust in workers engaged in any operation underground in coal mines, in screens workers at collieries and in coaltrimmers at docks.

PREVENTION OF UNDERGROUND ATMOSPHERIC CONDITIONS HAZARDOUS TO HEALTH

For the sake of brevity, only general preventive measures for the control of health hazards from inadequate mine ventilation are discussed. More detailed information can be obtained by readers from voluminous reports in the literature on this subject.

Adequate ventilation of underground mine workings is the most important means of controlling gases and dust in mines. It comprises establishment of such control of air currents that underground workers may work in safety with maximum comfort and efficiency and without impairment of health; that the air flow in mine openings may be made subject to such control as to remove harmful gases and dusts from the workings at ordinary times; and that in an emergency, such as fire or explosion, as much or as little air flow may be maintained as desired in parts of the mine or in the mine in its entirety (10).

The importance of ventilation in mines is indicated by the fact that it is regulated by law in some States. In these States, the basis of calculation is the quantity of air to be supplied per person and per animal underground rather than the quality from the standpoint of health and comfort of those exposed thereto. Requirements range from the indefinite "operators must furnish good ventilation" or "sufficient current of fresh air for health and safety of miners" in some States to a more or less definite "not less than 85 cubic feet per minute per person and 500 per animal," and "150 cubic feet per minute per person and 600 per animal in gassy mines" in other States. For example, the law for Maryland (20) (as of March 22, 1937) contains the following provisions regarding ventilation of mines:

> Mines are to be ventilated so as to dilute, carry off, and render harmless all noxious or dangerous gases, affording in nongaseous mines not less than 100 cu.

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ft. of air per minute per person, and 300 cu. ft. of air per minute per animal, and in gaseous mines, a minimum of 150 cu. ft. of air per minute per person, and 500 cu. ft. of air per minute per animal (art. 89, sec. 99). Mining ventilation to be split so that not more than 75 men share same source of ventilation; provision also, that in gaseous mines, District Mine Inspector may require split of ventilation per smaller unit group of men (art. 89, sec. 101). Mines employing more than 10 persons at any one time, unless required ventilation is provided by other approved means, not a furnace, the current therefor should be provided by fan of substantial type (art. 89, sec. 103).

The Bureau of Mines (21) makes the following recommendations regarding the quantity of air to be supplied to underground workers:

The quantity in cubic feet per minute of pure air in any split, circulated through the last open crosscut, should be not less than 200 times the number of men working in the section, and as much more as may be required.

The quantity of air reaching the last open crosscut on any pair of working entries, headings, or gangways, or the maximum inby point of a split should be at least 6,000 cubic feet per minute.

The quantity of air reaching the face of each working place should be at least 200 cubic feet per minute per man employed and as much more as may be necessary to dilute and carry away any inflammable or harmful gases that may be present.

All entries, rooms, panels, or sections that cannot be kept well-ventilated throughout and regularly inspected, or that are not being used for coursing the air, travel, haulage, or the extraction of coal, should be sealed by strong, fireproof stoppings and provided with some means of bleeding-off the gas into the return.

Prevention of Poisoning by Mine Gases

In addition to good ventilation to dilute and carry away the gases, other preventive measures are: Avoidance of exposure to air known to contain poisonous gases; use of adequate protective equipment when atmospheres known to contain poisonous gases are to be encountered; keeping calm when it is necessary to enter or be exposed unprotected to atmospheres containing gases; not

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hurrying but getting to fresh air as quickly, and with as little exertion, as possible; and using methods of mining or tunneling, blasting, and mucking that will minimize the occurrence of the gases or their release.

Control of Dust Hazard in Mines

There are two main lines of approach to the problem of dust-disease prevention in industry - the engineering, through control of dust production, and the medical, through preemployment and periodic physical examination of workers; success depends on a combination of the two.

As dust is the greatest contributor to the excessive mortality from pulmonary diseases in the mining industry, the principal method of preventing these diseases is to eliminate as far as possible or reduce to harmless concentrations the dust to which workers are exposed. The principal measures for doing this in mining operations are ventilation, wet methods, proper blasting practice, and the use of personal respiratory protection.

Analysis of data collected by the Public Health Service to determine safe limits of dust exposure indicate that employment in an atmosphere containing less than 50 million dust particles per cubic foot produces a negligible number of cases of silicosis when the quartz content of the dust is less than 5 percent; when the silica content is about 13 percent 10 to 15 million particles appears to be a safe limit; when the quartz content is higher 4 million particles probably would be a safer limit under some conditions.

Although, strictly speaking, preemployment and periodic physical examination is not a dust-control measure, it is an important means of determining the efficacy of the methods employed to reduce the dust hazard. If workers exposed to dust are examined periodically, early manifestations of respiratory disease can be discovered and measures taken to reduce the amount of dust in the air or to transfer affected workers to a less hazardous environment.

Treatment of Poisoning by Mine Gases

The steps in effective treatment of acute poisoning by noxious gases are:

1. The victim should be removed to fresh air as soon as possible.

2. If breathing has stopped, is weak and intermittent, or is present in only occasional gasps, artificial respiration by the Schaefer method should be

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given persistently until normal breathing is resumed or until a physician declares that the patient is dead.

3. Circulation should be aided by rubbing the limbs toward the body trunk and by keeping the body warm with blankets, hot-water bottles, hot bricks, or other devices, care being taken that these are wrapped or do not come in contact with the body and produce burns. This aids in tiding the body over a period of low vitality. Other stimulants, such as hypodermics of caffein, sodium benzoate, or camphor in oil, should only be administered by a physician after he has considered the possibility of overstimulation and consequent collapse.

4. The patient should be kept at rest, lying down, to avoid any strain on the heart. Later, he should be treated as a convalescent and given plenty of time to rest and recuperate.

5. Aftereffects of poisoning by such gases should be treated symptomatically.

6. It should be emphasized that inhalations, for 20 to 30 minutes, of oxygen or a 5-percent mixture of carbon dioxide in oxygen, if available, will immediately greatly reduce the number and severity of symptoms of carbon monoxide poisoning, as well as decrease the possibility of serious consequences. All industries in which this type of poisoning commonly exists should provide apparatus (inhalers) for the efficient administration of these treatments. The apparatus should be placed at points most convenient for treating carbon monoxide poisoning, and employees should be trained in their use so that resuscitation may be effected immediately.

Treatment of Dust Diseases

The treatment of anthracosilicosis is symptomatic. The treatment of other respiratory diseases that occur more frequently among miners, such as bronchitis, pneumonia, and tuberculosis, need not be discussed in this paper.

Mortality and morbidity from pulmonary diseases are excessive in the mining industry as a result of exposure to large quantities of dust in the air breathed. Therefore, control of the dust hazard is necessary to prevent these diseases. No single measure of control is applicable to all dusty operations and processes; therefore, all the means of prevention must be practiced to insure success in the solution of the problem.

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